AD-A243 429

TECHNICAL REPORT ARCCB-TR-91033

RESIDUAL STRESSES IN A PRESTRESSED STEEL PRESSURE VESSEL WRAPPED WITH MULTILAYERED COMPOSITES

PETER C. T. CHEN

DTIC
ELECTE
DEC 17, 1991
S B D

NOVEMBER 1991

US ARMY ARMAMENT RESEARCH, DEVELOPMENT AND ENGINEERING CENTER
CLOSE COMBAT ARMAMENTS CENTER
BENÉT LABORATORIES
WATERVLIET, N.Y. 12189-4050

BENÉT LABS

91 1216 025

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

91-18063

DISCLAIMER

The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

The use of trade name(s) and/or manufacturer(s) does not constitute an official indorsement or approval.

DESTRUCTION NOTICE

For classified documents, follow the procedures in DoD 5200.22-M, Industrial Security Manual, Section II-19 or DoD 5200.1-R, Information Security Program Regulation, Chapter IX.

For unclassified, limited documents, destroy by any method that will prevent disclosure of contents or reconstruction of the document.

For unclassified, unlimited documents, destroy when the report is no longer needed. Do not return it to the originator.

REPORT DOCUMENTATION PAGE

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	November 1991	Final

4. TITLE AND SUBTITLE

RESIDUAL STRESSES IN A PRESTRESSED STEEL PRESSURE VESSEL WRAPPED WITH MULTILAYERED COMPOSITES

5. FUNDING NUMBERS

AMCMS No. 6126.24.H190.011
PRON No. 1A07Z0CBNMSC

6. AUTHOR(S)

Peter C.T. Chen

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

U.S. Army ARDEC
Benet Laboratories, SMCAR-CCB-TL
Watervliet, NY 12189-4050

8. PERFORMING ORGANIZATION REPORT NUMBER

ARCCB-TR-91033

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

U.S. Army ARDEC
Close Combat Armaments Center
Picatinny Arsenal, NJ 07806-5000

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

Presented at the Sixth Technical Conference of the American Society for Composites, Albany, NY, 6-9 October 1991.
Published in Proceedings of the Conference.

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

This report presents an analytical solution for predicting residual stresses in a steel pressure vessel wrapped with a multilayered composite jacket. The numerical results for the hoop stresses before and after complete unloading are obtained for a subscale test tube. The steel liner is elastic-plastic, and the composite layup $(0_2 90_2)_4$ consists of 16 layers made of graphite-bismaleimide produced by Fiberite Corporation.

14. SUBJECT TERMS

Residual Stresses, Pressure Vessel, Composite Materials, Autofrettage, Elastic-Plastic, Steel Tube

15. NUMBER OF PAGES

13

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

TABLE OF CONTENTS

TABLES

LIST OF ILLUSTRATIONS

i

INTRODUCTION

In recent years there has been increasing emphasis on the use of composite materials in armament structures. A current problem in Army cannon design is to replace a portion of the steel wall thickness with a lighter material. The inner portion, steel liner, maintains the tube projectile interface and shields the composite from the extremely hot gases. The outer portion, composite jacket, is made of single or multilayered graphite-bismaleimide wound and wrapped on the steel liner. Two subscale models have been fabricated and tested (refs 1,2). An analytical elastic-plastic solution for the model with a single-layered composite jacket has been presented in a recent paper (ref 3). This report covers a complete stress analysis for the model with a multilayered composite jacket. The composite layup is made of two longitudinal layers alternating with two circumferential layers. Sixteen layers were applied in this way. The total thickness of the composite jacket is 0.12 inch and the steel liner is of inner radius 1 inch and outer radius 1.17 inches. Analytical solutions are presented for loading within and beyond the elastic range up to failure. Numerical results for the residual stresses in the steel liner and composite jacket are presented.

COMPOSITE JACKET

The composite jacket is made of n layers bounded by radii $(r_1, r_2, \ldots, r_n, r_{n+1})$. Each layer is elastically orthotropic but with different material properties. The strain-stress relations for the k-th layer in cylindrical coordinates are given by

$$\begin{Bmatrix} \epsilon_r^{(k)} \\ \epsilon_\theta^{(k)} \\ \epsilon_z^{(k)} \end{Bmatrix} = \begin{bmatrix} 1/E_r & , & -\nu_{\theta r}/E_\theta & -\nu_{zr}/E_z \\ -\nu_{r\theta}/E_r & , & 1/E_\theta & -\nu_{z\theta}/E_\theta \\ -\nu_{rz}/E_r & , & -\nu_{\theta z}/E_\theta & 1/E_z \end{bmatrix}^{(k)} \begin{Bmatrix} \sigma_r^{(k)} \\ \sigma_\theta^{(k)} \\ \sigma_z^{(k)} \end{Bmatrix} \tag{1}$$

1

or

$$\epsilon_i{}^{(k)} = S_{ij}{}^{(k)} \sigma_j{}^{(k)} \quad (i,j = r,\theta,z) \tag{2}$$

where $S_{ij}{}^{(k)}$ are components of the compliance matrix. The superscript k refers to the k-th layer. In plane-strain conditions, the above strain-stress relations modify to

$$\begin{Bmatrix} \epsilon_r{}^{(k)} \\ \epsilon_\theta{}^{(k)} \end{Bmatrix} = \begin{bmatrix} \beta_{rr}{}^{(k)} & \beta_{r\theta}{}^{(k)} \\ \beta_{r\theta}{}^{(k)} & \beta_{\theta\theta}{}^{(k)} \end{bmatrix} \begin{Bmatrix} \sigma_r{}^{(k)} \\ \sigma_\theta{}^{(k)} \end{Bmatrix} \tag{3}$$

where

$$\beta_{rr}{}^{(k)} = (1 - \nu_{rz}{}^{(k)}\nu_{zr}{}^{(k)})/E_r{}^{(k)}$$

$$\beta_{r\theta}{}^{(k)} = -(\nu_{\theta r}{}^{(k)} + \nu_{\theta z}{}^{(k)}\nu_{zr}{}^{(k)})/E_\theta{}^{(k)}$$

$$\beta_{\theta\theta}{}^{(k)} = (1 - \nu_{\theta z}{}^{(k)}\nu_{z\theta}{}^{(k)})/E_\theta{}^{(k)} \tag{4}$$

The normal traction acting on the interface between (k-1)th and k-th layers is denoted by q_k. Then the general elastic solution for the k-th layer bounded by radii (r_k, r_{k+1}) and subjected to interface pressure (q_k, q_{k+1}) is given by (ref 4)

$$\sigma_r{}^{(k)} = (-a_k q_k + c_k q_{k+1})(r_{k+1}/r)^{g_k+1} + (a_k q_k - b_k q_{k+1})(r/r_{k+1})^{g_k-1}$$

$$\sigma_\theta{}^{(k)} = g_k(a_k q_k - c_k q_{k+1})(r_{k+1}/r)^{g_k+1} + g_k(a_k q_k - b_k q_{k+1})(r/r_{k+1})^{g_k-1}$$

$$u^{(k)} = r(\beta_{r\theta}{}^{(k)}\sigma_r{}^{(k)} + \beta_{\theta\theta}{}^{(k)}\sigma_\theta{}^{(k)}) \tag{5}$$

where

$$d_k = r_{k+1}/r_k \quad , \quad g_k = (\beta_{rr}{}^{(k)}/\beta_{\theta\theta}{}^{(k)})^{\frac{1}{2}}$$

$$c_k = (d_k{}^{2g_k} - 1)^{-1} \quad , \quad b_k = c_k d_k{}^{2g_k} \quad , \quad a_k = c_k d_k{}^{g_k-1} \tag{6}$$

At the two ends of the k-th layer the expressions for the displacements and hoop stresses are

$$u_{k+1} = (A_k q_k - B_k q_{k+1}) r_{k+1}$$

$$u_k = (C_k q_k - D_k q_{k+1}) r_k$$

$$\sigma_\theta^{(k)} = 2a_k g_k q_k - (b_k+c_k) g_k q_{k+1} \quad \text{at } r_{k+1}$$

$$\sigma_\theta^{(k)} = (b_k+c_k) g_k q_k - 2a_k d_k^2 g_k q_{k+1} \quad \text{at } r_k \qquad (7)$$

where

$$A_k = 2a_k g_k \beta_{\theta\theta}^{(k)} \quad , \quad B_k = \beta_{r\theta}^{(k)} + (b_k+c_k) g_k \beta_{\theta\theta}^{(k)}$$

$$C_k = -\beta_{r\theta}^{(k)} + (b_k+c_k) g_k \beta_{\theta\theta}^{(k)} \quad , \quad D_k = 2a_k d_k^2 g_k \beta_{\theta\theta}^{(k)} \qquad (8)$$

At the interfaces ($r_k, k=2,\ldots,n$) the displacements should be continuous and these require

$$A_{k-1} q_{k-1} - B_{k-1} q_k = C_k q_k - D_k q_{k+1} \qquad (9)$$

Let $\bar{Q}_k = q_k/q_n$ for all k, then $\bar{Q}_{n+1} = 0$, $\bar{Q}_n = 1$, and we can calculate $\bar{Q}_{k-1}$ backward for $k = n$ to 2 by

$$\bar{Q}_{k-1} = A_{k-1}^{-1}[(B_{k-1}+C_k)\bar{Q}_k - D_k\bar{Q}_{k+1}]$$

Normalizing by $\bar{Q}_1$ leads to

$$\bar{q}_k = q_k/q_1 \quad \text{for } k = 1,2,\ldots,n \qquad (10)$$

i.e., the relative values for the interface pressures when $q_1 = 1$. We can also obtain the corresponding displacements $\bar{u}_1,\ldots,\bar{u}_n,\ \bar{u}_{n+1}$ at $r_1,\ldots,r_n,r_{n+1}$.

STEEL LINER

The steel liner of inside radius a and outer radius b is elastic-plastically isotropic and assumed to obey Tresca's yield criterion, the associated flow rule, and linear strain-hardening. The elastic solution for the steel liner subjected to internal pressure p and external pressure q is

$$\begin{matrix} \sigma_r \\ \\ \sigma_\theta \end{matrix} = \{\mp(p-q)(b/r)^2 + p-q\ b^2/a^2\}/(b^2/a^2-1)$$

$$u/r = E^{-1}(1+\nu)[(p-q)(b/r)^2 + (1-2\nu)(p-q\ b^2/a^2)]/(b^2/a^2-1) \qquad (11)$$

3

When the internal pressure p is large enough, part of the steel liner ($a \leqslant r \leqslant \rho$) will become plastic and ρ is the elastic-plastic interface. The elastic-plastic solution can be written in the elastic portion ($\rho \leqslant r \leqslant b$) as

$$\frac{E}{\sigma_0} \frac{u}{r} = \frac{1+\nu}{2} \frac{\rho^2}{r^2} + (1-\nu-2\nu^2)[\frac{1}{2} \frac{\rho^2}{b^2} - \frac{q}{\sigma_0}]$$

$$\begin{matrix} \sigma_r/\sigma_0 \\ \\ \sigma_\theta/\sigma_0 \end{matrix} = \frac{1}{2}(\mp \frac{\rho^2}{r^2} + \frac{\rho^2}{b^2}) - \frac{q}{\sigma_0}$$

$$\sigma_z/\sigma_0 = \nu \, \rho^2/b^2 - 2\nu \, q/\sigma_0 \qquad\qquad (12)$$

and in the plastic portion ($a \leqslant r \leqslant \rho$)

$$\frac{E}{\sigma_0} \frac{u}{r} = (1-\nu-2\nu^2) \frac{\sigma_r}{\sigma_0} + (1-\nu^2) \frac{\rho^2}{r^2}$$

$$\begin{matrix} \sigma_r/\sigma_0 \\ \\ \sigma_\theta/\sigma_0 \end{matrix} = \mp \frac{1}{2} (1-\eta\beta+\eta\beta \frac{\rho^2}{r^2}) + \frac{1}{2} \frac{\rho^2}{b^2} - (1-\eta\beta)\ln \frac{\rho}{r} - \frac{q}{\sigma_0}$$

$$\sigma_z/\sigma_0 = \nu \, \rho^2/b^2 - 2\nu(1-\eta\beta)\ln \frac{\rho}{r} - 2\nu \, q/\sigma_0$$

$$\bar{\epsilon}^p = \beta(\rho^2/r^2-1) \quad , \quad \eta\beta = \frac{m}{m + \frac{3}{4} \frac{(1-m)}{(1-\nu^2)}}$$

$$\eta = -\frac{2}{\sqrt{3}} \frac{E}{\sigma_0} \frac{m}{1-m} \quad , \quad m = \frac{E_t}{E} \quad , \quad \sigma = \sigma_0(1+\eta\bar{\epsilon}^p) \qquad (13)$$

where σ_0 is the initial tensile yield stress and E_t is the tangent modulus in the plastic range of the stress-strain curve.

When the internal pressure is further increased, the steel liner will become fully-plastic. Using Tresca's yield criterion, the associated flow rule, and assuming linear strain-hardening, the fully-plastic solution derived in Reference 3 is given below.

Subject to $\sigma_\theta \geqslant \sigma_z \geqslant \sigma_r$, the analytical expressions for the stresses and displacement are

$$\sigma_r = -p + \sigma_0(1-\eta\beta)\ln(\tfrac{r}{a}) + \frac{1}{2} \frac{\eta\beta}{(1-\nu^2)} [\tfrac{b^2}{a^2} - \tfrac{b^2}{r^2}]E\phi$$

$$\sigma_\theta = \sigma_r + \sigma_0(1+\eta\epsilon^p)$$

$$ru = E^{-1}(1-2\nu)(1+\nu)r^2\sigma_r + \phi\, b^2 \tag{14}$$

where

$$\phi = u_b/b + (1-2\nu)(1+\nu)E^{-1}q$$

$$\bar\epsilon^p = \frac{2}{\sqrt{3}} [\phi\, b^2/r^2 - (1-\nu^2)\sigma_0/E]/[1 + \frac{2}{\sqrt{3}}(1-\nu^2)\eta\sigma_0/E]$$

COMPOUND CYLINDER

The compound cylinder consists of an inner steel liner and an outer composite jacket. The steel liner of inside radius a and outer radius b is wrapped by a multilayered composite jacket. The displacement and normal traction at the interface between the liner and jacket should be continuous, i.e., $q = q_1$ and $u_b = u_1$. From these conditions we can determine the relations between p and q.

When the internal pressure p is small, an explicit functional relation exists

$$\frac{2p}{q} = \frac{(b^2/a^2-1)}{(1-\nu^2)} [E(C_1-D_1\bar{q}_2) + (1-\nu-2\nu^2)] + 2 \tag{15}$$

where every term in the right-hand side is known. The displacement at the bore can also be expressed as an explicit function of p

$$(\tfrac{b^2}{a^2} - 1) \frac{E}{p} \frac{u_a}{a} = (1+\nu) \tfrac{b^2}{a^2} + (1-\nu-2\nu^2) - 2(1-\nu^2) \tfrac{b^2}{a^2} \frac{q}{p} \tag{16}$$

When the internal pressure is large enough, part of the steel liner will become plastic. The elastic-plastic solution is given in terms of the parameter ρ. The conditions of continuity require

$$\frac{q}{\sigma_0} = \frac{(1-\nu^2)\rho^2/b^2}{(1-\nu-2\nu^2) + E(C_1-D_1\bar{q}_2)} \tag{17}$$

5

This, together with

$$\frac{p}{\sigma_0} = \frac{q}{\sigma_0} + \frac{1}{2}(1 - \frac{\rho^2}{b^2}) + (1-\eta\beta)\ln\frac{\rho}{a} + \frac{\eta\beta}{2}(\frac{\rho^2}{a^2} - 1) \qquad (18)$$

serves to give an implicit relation between p and q. By letting ρ = a and b, we can determine the lower limits p*, q*, u_a*, u_b* and the upper limits p**, q**, u_a**, u_b**, respectively.

When the internal pressure p is further increased, i.e., p > p**, u_a > u_a**, u_b > u_b**, the conditions of continuity lead to

$$\phi = q[(C_1 - D_i\bar{q}_2) + (1-\nu-2\nu^2)/E] \qquad (19)$$

and

$$\frac{p}{\sigma_0} = (1-\eta\beta)\ln\frac{b}{a} + \frac{q}{\sigma_0}\left\{1 + \frac{\eta\beta(b^2/a^2-1)}{2(1-\nu^2)}[E(C_1-D_1\bar{q}_2) + (1-\nu-2\nu^2)]\right\} \qquad (20)$$

It should be pointed out that the pressure q and the displacement u_b at the interface are linear functions of internal pressure p. The bore displacement u_a can be written as

$$\frac{u_a}{a} = -(1-2\nu)(1+\nu)\frac{p}{E} + \frac{b^2}{a^2}\phi \qquad (21)$$

which is also a linear function of internal pressure p.

RESIDUAL STATE

If the pressure p is subsequently removed completely with no reverse yielding, the unloading is entirely elastic and the solution, denoted by a prime, is given by p' = -p.

$$q' = 2p'/\left\{\frac{(b^2/a^2-1)}{(1-\nu^2)}[E(C_1-D_1\bar{q}_2) + (1-\nu-2\nu^2)] + 2\right\}$$

$$\begin{matrix}\sigma_r' \\ \\ \sigma_\theta'\end{matrix} = \{\mp(p'-q')(b/r)^2 + p'-q'\,b^2/a^2\}/(b^2/a^2-1)$$

and

$$U'/r = E^{-1}(1+\nu)[(p'-q')(b/r)^2 + (1-2\nu)(p'-q'\,b^2/a^2)](b^2/a^2-1) \qquad (22)$$

6

The residual state system, denoted by two primes, is the sum of the system pro-
duced by loading and that produced by unloading, i.e.,

$$\sigma_\theta{}'' = \sigma_\theta + \sigma_\theta{}' \text{ , etc.} \tag{23}$$

Assuming no Bauschinger effect and using Tresca's yield criterion subject to
$\sigma_r{}'' > \sigma_z{}'' > \sigma_\theta{}''$, the reverse yielding will not occur if

$$\sigma_r{}'' - \sigma_\theta{}'' \leqslant \sigma'' = \sigma_0[1 + m\xi/(1-m)] \tag{24}$$

Unloading solution considering reverse yielding but neglecting Bauschinger
effect was first obtained by Bland (ref 5). If we need to consider the
Bauschinger effect during unloading, analytical solutions given in References 6
and 7 can be used.

NUMERICAL RESULTS

Given any value of internal pressure, we can obtain numerical results for
the stresses and strains in the radial and tangential directions and also for
the displacement at any radial position in a steel pressure vessel wrapped with
multilayered composites. The steel liner for the subscale test specimens
(ref 1) had an inner diameter of 2.0 inches and an outer diameter of 2.34
inches. The steel was 4130 seamless mechanical tubing heat treated to a hard-
ness of 34 to 36 Rockwell "C." A standard ASTM tensile test was conducted to
determine the 0.1 percent offset yield strength (120 Ksi) and the ultimate ten-
sile strength (140 Ksi). The composite jacket is a graphite-bismaleimide pro-
duced by Fiberite Corporation. Its cure temperature is 450°F, and it is wound
and wrapped on the steel liner in the same manner as the full-scale gun tube
specimen denoted as CTL III. The layup $(0_2 90_2)_4$ is approximately half-scale and
made up of two longitudinal layers alternating with two circumferential layers.
Sixteen layers are applied in this way. Lamina properties for this material are

given in Table I. The total thickness of the composite jacket is 0.12 inch, and the steel liner is assumed to be linear strain-hardening with a = 1 inch, b = 1.17 inches, σ_0 = 120 Ksi, m = 0.04.

TABLE I. ELASTIC CONSTANTS OF STEEL AND COMPOSITE MATERIALS

Material	E_θ x10⁶ psi	E_r x10⁶ psi	E_z x10⁶ psi	v_{rz}	$v_{r\theta}$	$v_{z\theta}$
Hoop lamina Im6	21.0	1.0	1.0	0.40	0.02	0.02
Axial lamina G50	1.3	1.3	31.0	0.01	0.39	0.39
Steel 4130	30.8	30.8	30.8	0.30	0.30	0.30

The pressure at the interface between the liner and jacket has been obtained as a function of internal pressure, and the result is shown in Figure 1. The results of the hoop strains at the bore, interface between the liner and jacket, and outside surface are shown in Figure 2 as functions of internal pressure. The complete (including elastic, elastic-plastic, and fully-plastic) ranges of loadings have been considered. These numerical results for the strains are presented here for future comparisons with experimental results. The distribution of hoop stresses in the liner and jacket can be obtained at any given value of internal pressure. In Figure 3 we present the numerical results at three values of internal pressure, i.e., p = p*, p**, and p = 21.33 Ksi when half of the liner is plastic. The values of two limits for the elastic-plastic solution are p* = 18.80 Ksi and p** = 22.60 Ksi. If the pressure p is sub-sequently removed completely, the residual displacements, strains, and stresses can be obtained. In Figure 4, we show the distributions of residual hoop stresses in the liner and jacket corresponding to three values of internal pressure before unloading. When the jacket consists of alternating axial-hoop

lamina, the hoop stresses before and after unloading become discontinuous not only at the interface between the liner and jacket but also at all other inter-faces between axial and hoop lamina.

CONCLUSION

A method for predicting residual stresses in a steel pressure vessel wrapped with multilayered composites has been developed. Analytical expressions are presented for loading in the elastic-plastic as well as the fully-plastic range.

REFERENCES

1. M.A. Scavullo, M.D. Witherell, K. Miner, T.E. O'Brien, and W. Yaiser, "Experimental and Analytical Investigation of a Steel Pressure Vessel Overwrapped With Graphite Bismaleimide," ARDEC Technical Report ARCCB-TR-87013, Benet Weapons Laboratory, Watervliet, NY, May 1987.

2. M.D. Witherell and M.A. Scavullo, "An Investigation of Stresses and Strains in an Internally Pressurized, Composite-Jacketed Steel Cylinder," ARDEC Technical Report ARCCB-TR-88042, Benet Laboratories, Watervliet, NY, November 1988.

3. P.C.T. Chen, "Elastic-Plastic Analysis of a Thick-Walled Composite Tube Subjected to Internal Pressure," Transactions of the Seventh Army Conference on Applied Mathematics and Computing, February 1990, pp. 589-598.

4. S.W. Tsai, Composite Design, 3rd Edition, Think Composites, Dayton, OH, 1987.

5. D.R. Bland, "Elastoplastic Thick-Walled Tubes of Work-Hardening Material Subject to Internal and External Pressures and to Temperature Gradients," Journal of the Mechanics and Physics of Solids, Vol. 4, 1955, pp. 209-229.

6. P.C.T. Chen, "Bauschinger and Hardening Effects on Residual Stresses in Autofrettaged Thick-Walled Cylinders," Journal of Pressure Vessel Technology, Vol. 108, February 1986, pp. 108-112.

7. P.C.T. Chen, "Stress and Deformation Analysis of Autofrettaged High Pressure Vessels," ASME Pressure Vessels and Piping, Vol. 110, July 1986, pp. 61-67.
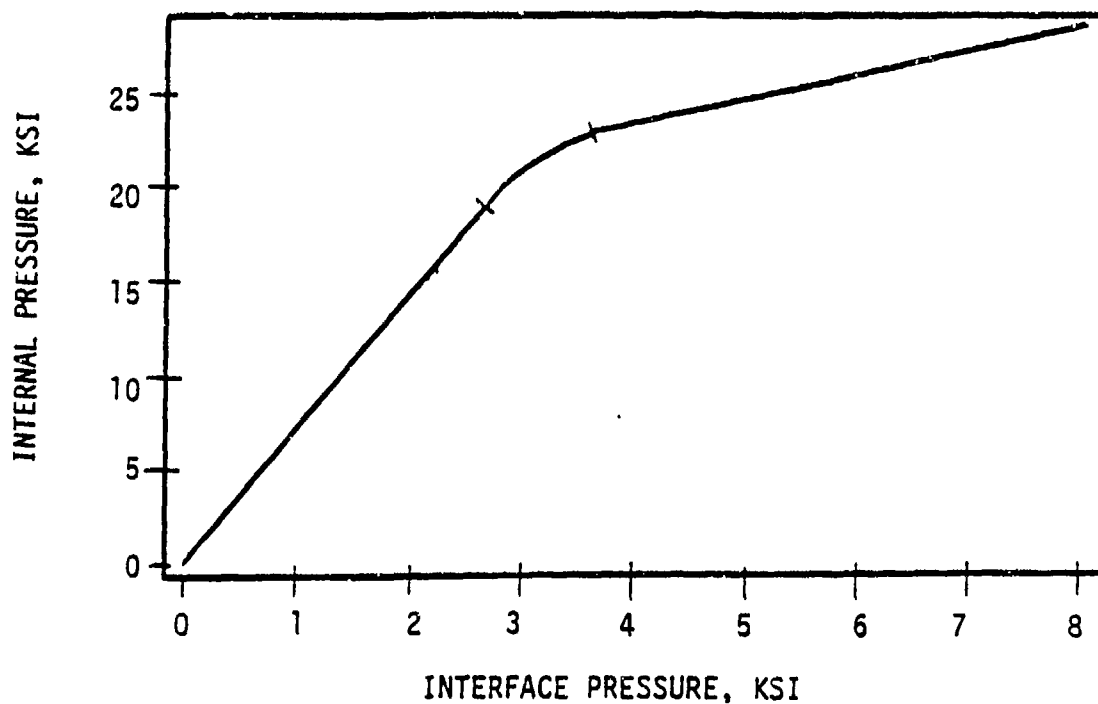
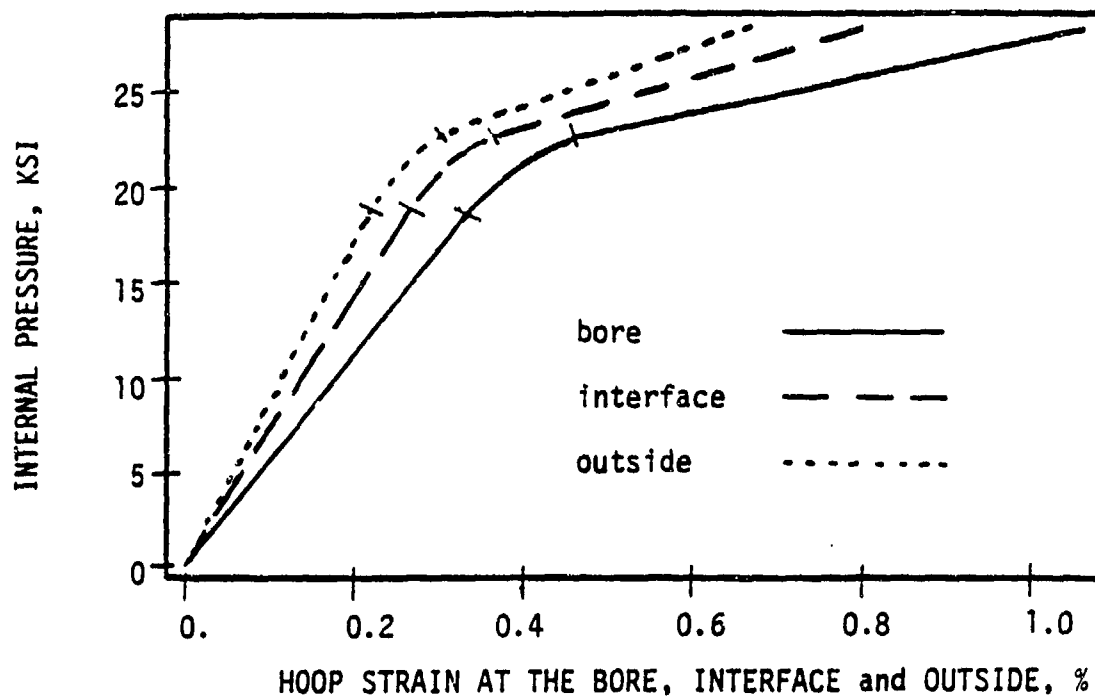Figure 1. Interface pressure as a function of internal pressure.

Figure 2. Hoop strains at the bore, interface, and outside
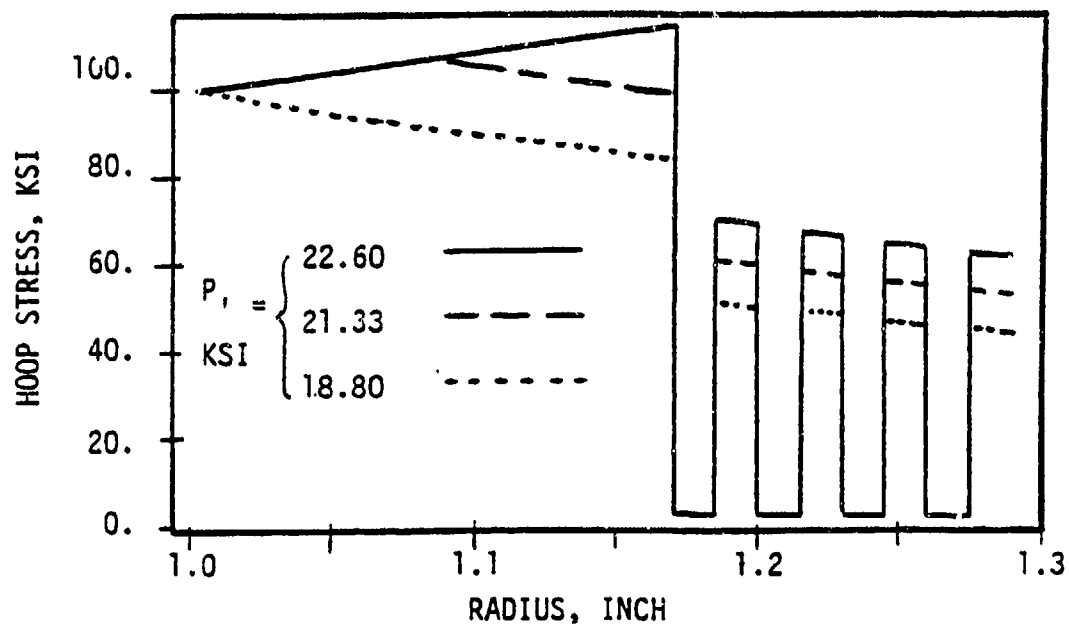as functions of internal pressure.

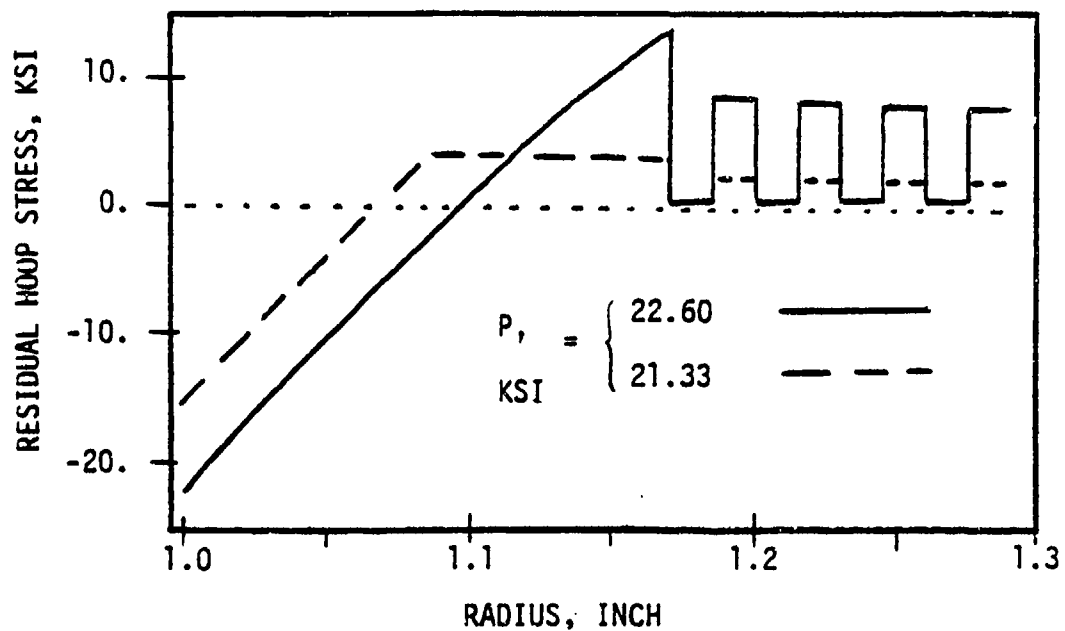Figure 3. Distribution of hoop stresses in the liner and jacket.

Figure 4. Distribution of residual hoop stresses in the liner and jacket.

TECHNICAL REPORT INTERNAL DISTRIBUTION LIST

	NO. OF COPIES
CHIEF, DEVELOPMENT ENGINEERING DIVISION ATTN: SMCAR-CCB-DA	1
-DC	1
-DI	1
-DR	1
-DS (SYSTEMS)	1
CHIEF, ENGINEERING SUPPORT DIVISION ATTN: SMCAR-CCB-S	1
-SD	1
-SE	1
CHIEF, RESEARCH DIVISION ATTN: SMCAR-CCB-R	2
-RA	1
-RE	1
-RM	1
-RP	1
-RT	1
TECHNICAL LIBRARY ATTN: SMCAR-CCB-TL	5
TECHNICAL PUBLICATIONS & EDITING SECTION ATTN: SMCAR-CCB-TL	3
OPERATIONS DIRECTORATE ATTN: SMCWV-ODP-P	1
DIRECTOR, PROCUREMENT DIRECTORATE ATTN: SMCWV-PP	1
DIRECTOR, PRODUCT ASSURANCE DIRECTORATE ATTN: SMCWV-QA	1

NOTE: PLEASE NOTIFY DIRECTOR, BENET LABORATORIES, ATTN: SMCAR-CCB-TL, OF ANY ADDRESS CHANGES.

TECHNICAL REPORT EXTERNAL DISTRIBUTION LIST

	NO. OF COPIES		NO. OF COPIES
ASST SEC OF THE ARMY RESEARCH AND DEVELOPMENT ATTN: DEPT FOR SCI AND TECH THE PENTAGON WASHINGTON, D.C. 20310-0103	1	COMMANDER ROCK ISLAND ARSENAL ATTN: SMCRI-ENM ROCK ISLAND, IL 61299-5000	1
ADMINISTRATOR DEFENSE TECHNICAL INFO CENTER ATTN: DTIC-FDAC CAMERON STATION ALEXANDRIA, VA 22304-6145	12	DIRECTOR US ARMY INDUSTRIAL BASE ENGR ACTV ATTN: AMXIB-P ROCK ISLAND, IL 61299-7260	1
COMMANDER US ARMY ARDEC ATTN: SMCAR-AEE	1	COMMANDER US ARMY TANK-AUTMV R&D COMMAND ATTN: AMSTA-DDL (TECH LIB) WARREN, MI 48397-5000	1
SMCAR-AES, BLDG. 321	1		
SMCAR-AET-O, BLDG. 351N	1	COMMANDER	
SMCAR-CC	1	US MILITARY ACADEMY	1
SMCAR-CCP-A	1	ATTN: DEPARTMENT OF MECHANICS	
SMCAR-FSA	1	WEST POINT, NY 10996-1792	
SMCAR-FSM-E	1		
SMCAR-FSS-D, BLDG. 94	1	US ARMY MISSILE COMMAND	
SMCAR-IMI-I (STINFO) BLDG. 59	2	REDSTONE SCIENTIFIC INFO CTR	2
PICATINNY ARSENAL, NJ 07806-5000		ATTN: DOCUMENTS SECT, BLDG. 4484 REDSTONE ARSENAL, AL 35898-5241	
DIRECTOR US ARMY BALLISTIC RESEARCH LABORATORY ATTN: SLCBR-DD-T, BLDG. 305 ABERDEEN PROVING GROUND, MD 21005-5066	1	COMMANDER US ARMY FGN SCIENCE AND TECH CTR ATTN: DRXST-SD 220 7TH STREET, N.E. CHARLOTTESVILLE, VA 22901	1
DIRECTOR US ARMY MATERIEL SYSTEMS ANALYSIS ACTV ATTN: AMXSY-MP ABERDEEN PROVING GROUND, MD 21005-5071	1	COMMANDER US ARMY LABCOM MATERIALS TECHNOLOGY LAB ATTN: SLCMT-IML (TECH LIB) WATERTOWN, MA 02172-0001	2
COMMANDER HQ, AMCCOM ATTN: AMSMC-IMP-L ROCK ISLAND, IL 61299-6000	1		

NOTE: PLEASE NOTIFY COMMANDER, ARMAMENT RESEARCH, DEVELOPMENT, AND ENGINEERING
       CENTER, US ARMY AMCCOM, ATTN: BENET LABORATORIES, SMCAR-CCB-TL,
       WATERVLIET, NY 12189-4050, OF ANY ADDRESS CHANGES.

	NO. OF COPIES		NO. OF COPIES
COMMANDER US ARMY LABCOM, ISA ATTN: SLCIS-IM-TL 2800 POWDER MILL ROAD ADELPHI, MD 20783-1145	1	COMMANDER AIR FORCE ARMAMENT LABORATORY ATTN: AFATL/MN EGLIN AFB, FL 32542-5434	1
COMMANDER US ARMY RESEARCH OFFICE ATTN: CHIEF, IPO P.O. BOX 12211 RESEARCH TRIANGLE PARK, NC 27709-2211	1	COMMANDER AIR FORCE ARMAMENT LABORATORY ATTN: AFATL/MNF EGLIN AFB, FL 32542-5434	1
DIRECTOR US NAVAL RESEARCH LAB ATTN: MATERIALS SCI & TECH DIVISION CODE 26-27 (DOC LIB) WASHINGTON, D.C. 20375	1 1	MIAC/CINDAS PURDUE UNIVERSITY 2595 YEAGER ROAD WEST LAFAYETTE, IN 47905	1
DIRECTOR US ARMY BALLISTIC RESEARCH LABORATORY ATTN: SLCBR-IB-M (DR. BRUCE BURNS) ABERDEEN PROVING GROUND, MD 21005-5066	1		

NOTE: PLEASE NOTIFY COMMANDER, ARMAMENT RESEARCH, DEVELOPMENT, AND ENGINEERING
CENTER, US ARMY AMCCOM, ATTN: BENET LABORATORIES, SMCAR-CCB-TL,
WATERVLIET, NY 12189-4050, OF ANY ADDRESS CHANGES.